AMBUSHED BY A LURKING VARIABLE

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ABSTRACT

In the formal study of design and analysis of experiments, it is often overlooked that a simple and straight-forward design can become complicated during analysis. Presented here is a specific case in which the design was readily apparent but where difficulties subsequently arose. Analysis, plagued by nonhomogeneity of variance and the suspicion of a lurking variable, is discussed.

INTRODUCTION

Answers to questions concerning the performance of a MLRS (Multiple Launcher Rocket System) bomblet were desired. The M42 is a small shaped-charge bomblet (figure 1), designed to detonate on impact causing a jet, comprised primarily of copper, to penetrate the armor which it has impacted. Many bomblets are placed within a time-fused rocket, which is flown over the target area. A charge within the rocket is ignited, causing the skin of the rocket to peel away. This allows the undetonated bomblets to be sprayed over the target area; as the bomblets fall to the ground, a portion of them will impact the target.

DESIGN

There were three questions about the performance of this munition to be answered. First, is there a difference in bomblet performance among vendors? In this study, performance of the bomblet was taken to be penetration depth of the jet into the target. This question is self-explanatory and we will only note that there were three vendors considered. Second, does the dispersing process have an effect on bomblet performance? Dispersing is the process by which the bomblets are delivered from the rocket to the target. In particular, the customer was concerned with the ignition of the charge within the rocket which causes the skin of the rocket to peel away. When this charge is ignited, the bomblets are subjected to a certain amount of force. The above question then becomes how does this force affect bomblet performance. In order to answer this question, one half of the bomblets went through the dispersing simulation before testing for penetration depth. Third, how does Standoff affect bomblet performance? Standoff is the distance above the target at which the bomblet is detonated. The customer was interested in bomblet performance where detonation occurs at four different heights above the target.

To answer these questions, an experimental design was developed (figure 2). A 2x3x4 factorial design with response, Penetration Depth, and with factors, Dispensing, Vendor, and Standoff was chosen. In consideration of available bomblets, six observations per cell were used. This design was then suggested to the customer who then contracted a third party to run the experiment.

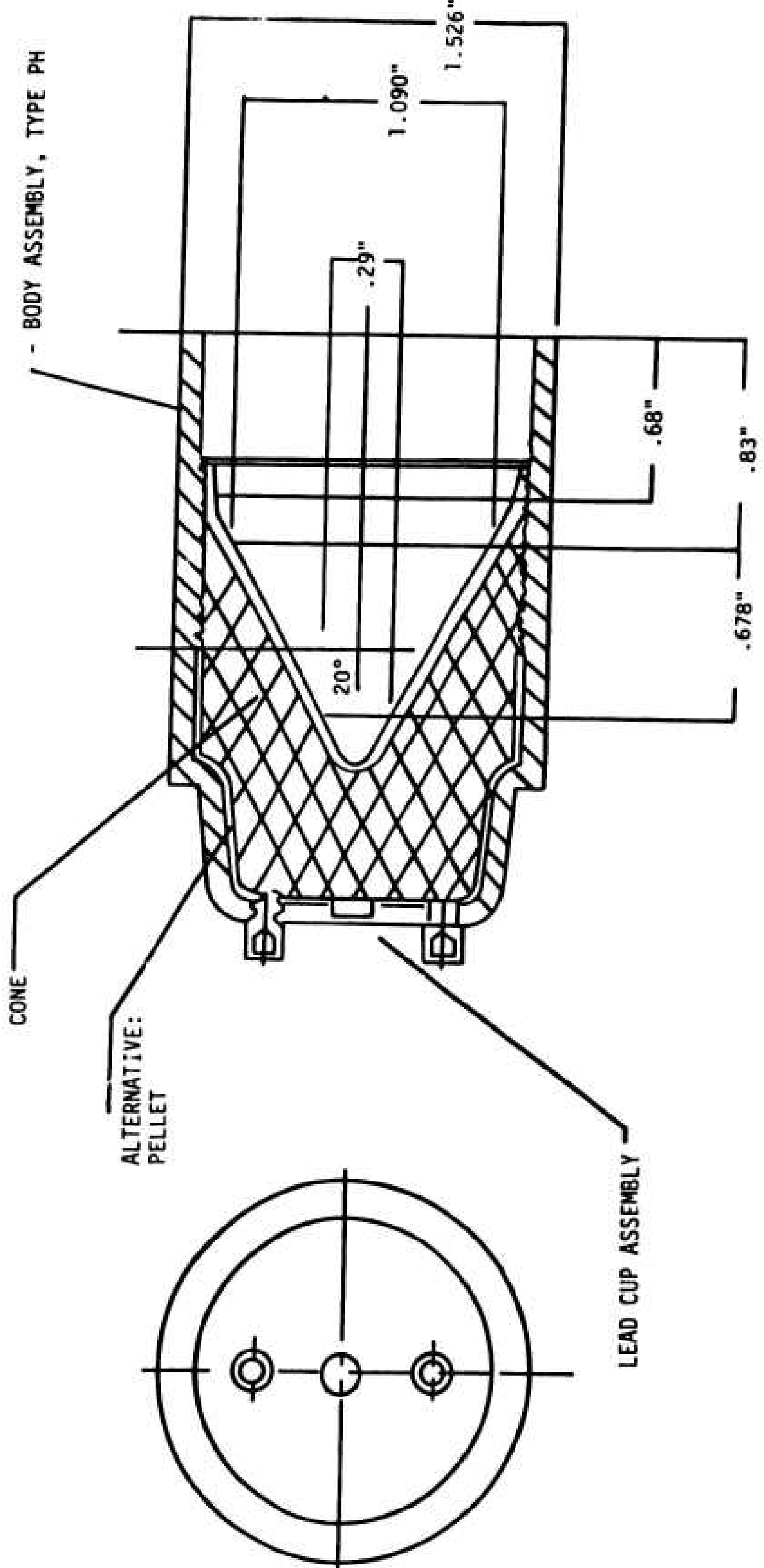

BODY ASSEMBLY, TYPE PH
1.526"
1.090"
.29"
.68"
.83"
.678"
20°
CONE
ALTERNATIVE:
PELLET
LEAD CUP ASSEMBLY

Fig. 1

STANDOFF

		.72"	3.86"	7.72"	15.44"
DISPERSED BOMBLETS	VENDOR 1	6 REPS			
	VENDOR 2				
	VENDOR 3				
NON-DISPERSED BOMBLETS	VENDOR 1				
	VENDOR 2				
	VENDOR 3				

FIGURE 2.

ANALYSIS

In examining the data, irregularities in the values caused us concern with respect to the usual model assumptions of normality, homogeneity of variance, and additivity. Prior to performing an analysis of variance, testing of those assumptions was begun. To test for normality, a Shapiro-Wilk test was run on the observations within cells. At the .05 significance level we found the results not inconsistent with the assumption of normality. Turning then to the question of homogeneity of variance, a plot (figure 3) of the cell means against the cell variances was constructed. When examining this graph, it was fairly obvious that conditions were somewhat less than ideal. Various corrective measures using the common transformations were unsuccessful in obtaining homogeneity of variance. Thus, efforts were begun to determine the cause of heterogeneity of variance.

A more critical look at the data revealed that within many of the cells representing dispersed bomblets there seemed to be two populations of data, a group of high values and a group of low values. Subjectively we flagged the lower values. Graphically (figure 4) we compared the means of the lower values and the means of the higher values within a given cell. On the plot, the symbol at the approximate coordinates (.75,.75) represents the mean of the lower values from vendor 1 at the first standoff. Noting the obvious difference between the mean of the lower and upper values within a given cell, we began to feel that maybe there were in fact two populations of data. It was at this point that we first suspected the existence of a lurking variable.

In mid stream we were asked to look at the effect of a new variable, Damage, which is a measure of 'out of round' of the bomblet. It was previously conjectured that the dispersing process may affect bomblet performance. Damage was an attempt at a more precise explanation of the possible effect of dispersing. In explaining how this measurement was taken, it is necessary that the testing sequence and apparatus first be described. First, bomblets are disarmed and, noting each bomblet position, loaded into a rocket-like canister comprised of five bomblet-holding packs (figure 5). The dispersing simulation involves exploding a charge within the canister causing bomblets to be sprayed over the test area. The bomblets are then gathered and measured for Damage, which is the absolute difference of two perpendicular measurements of bomblet diameter. After this simulation, the bomblets are armed and detonated at various heights over a plate of armor for the penetration depth data. Looking at this variable, Damage, led us to find our lurking variable.

Investigation of Damage brought out the following observations. First, those bomblets positioned in packs one and two during the dispersing simulation sustained a higher level of Damage than did those positioned in packs three through five. Second, those bomblets positioned in packs one and two during the dispersing simulation showed poorer penetration than did those in packs three through five. Third, high levels of Damage sustained by the bomblets adversely affected penetration performance. These observations are supported graphically by representative figures 6 and 7.

In figure 6, the symbol at the approximate coordinates (1.,3.75) represents the mean Damage sustained by bomblets, positioned in pack one during the dispersing simulation and then fired at the 7.72 inch standoff. The symbol at the approximate coordinates (1.,1.) represents the mean penetration depth achieved by those same bomblets. Note that in each graph the highest level of Damage is sustained by bomblets from pack one and that the level of damage decreases for bomblets from higher packs. Also the lowest mean penetration depth is exhibited by bomblets from pack one and generally increases for bomblets from higher packs. The apparent relationship between Damage and Penetration Depth was important, but not totally unexpected. More interesting and more important was the relationship of Pack to both Damage and Penetration Depth.

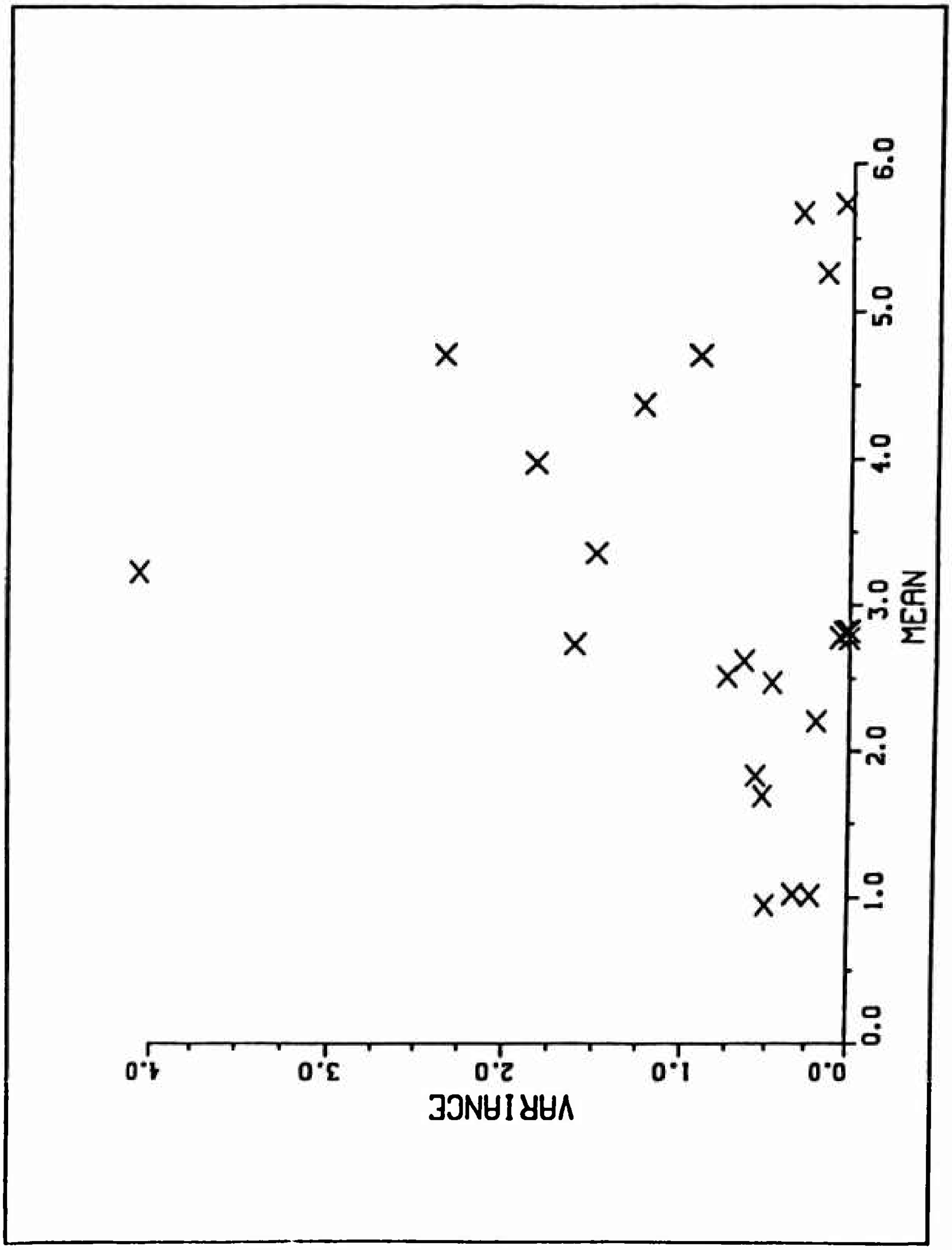


FIGURE 3.

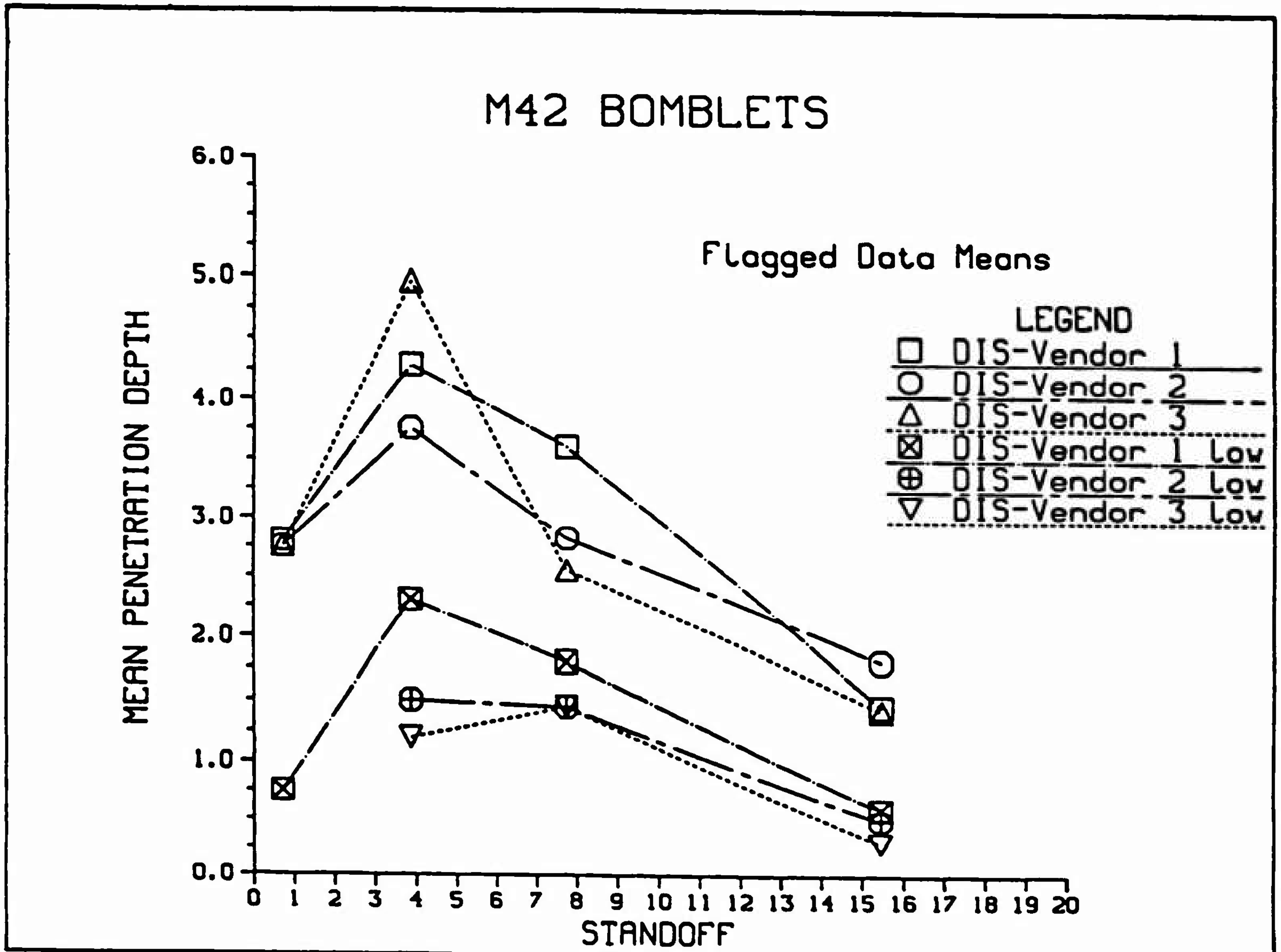

M42 BOMBLETS
Flagged Data Means
LEGEND
DIS-Vendor 1
DIS-Vendor 2
DIS-Vendor 3
DIS-Vendor 1 Low
DIS-Vendor 2 Low
DIS-Vendor 3 Low
MEAN PENETRATION DEPTH
0.0
1.0
2.0
3.0
4.0
5.0
6.0
STANDOFF
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

FIGURE 4.

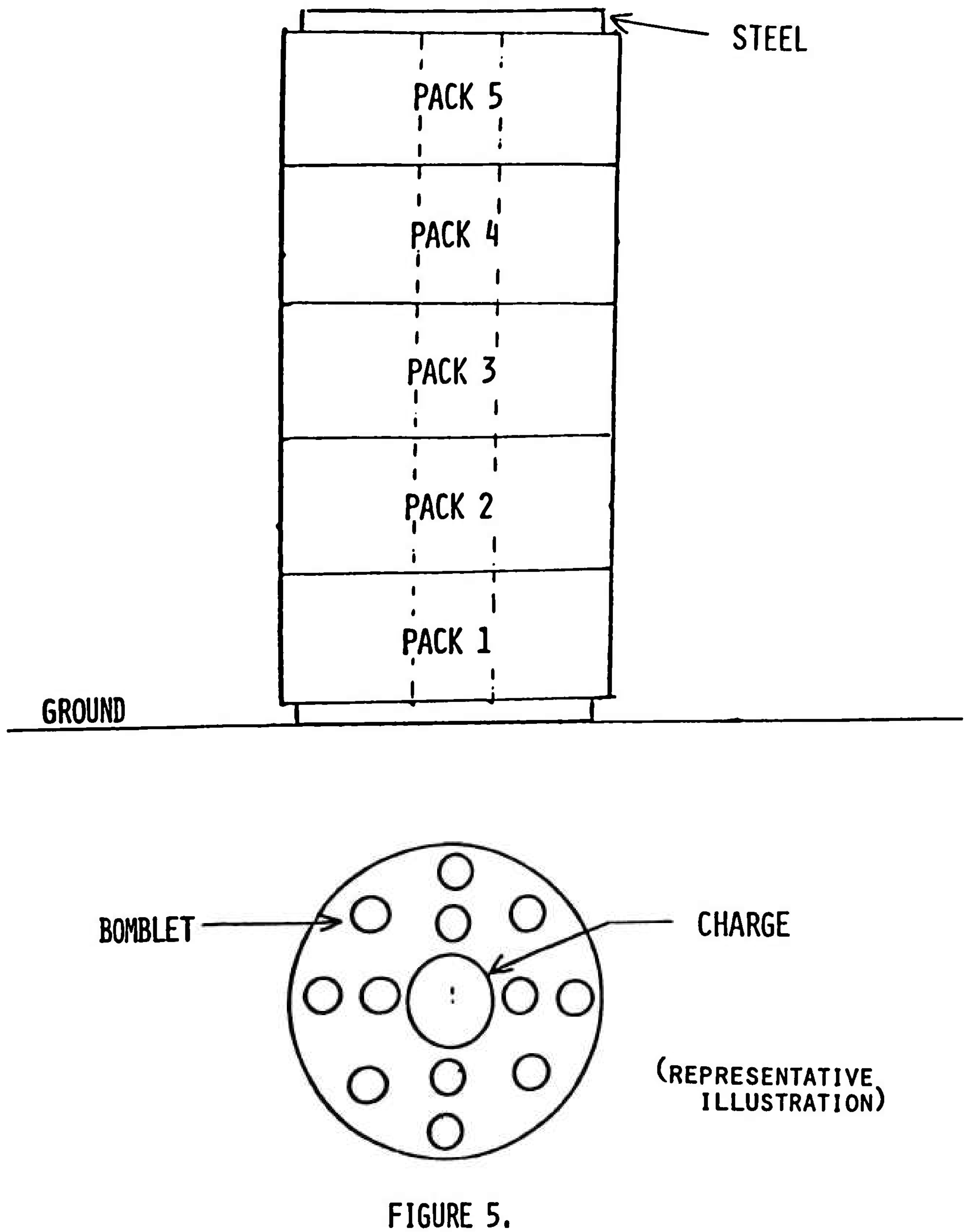
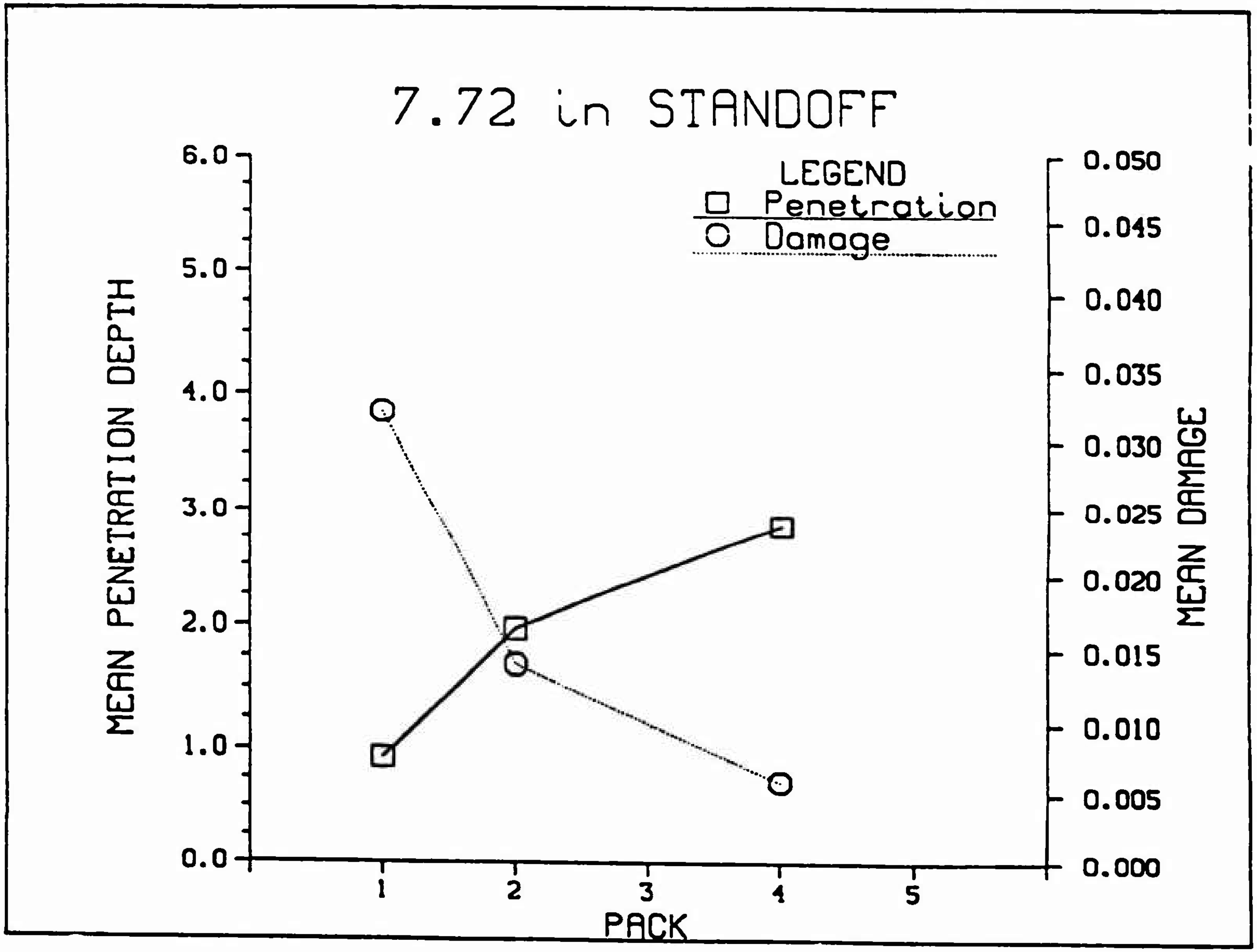

STEEL
PACK 5
PACK 4
PACK 3
PACK 2
PACK 1
GROUND
BOMBLET
CHARGE
(REPRESENTATIVE ILLUSTRATION)

FIGURE 5.



7.72 in STANDOFF
LEGEND
Penetration
Damage
MEAN PENETRATION DEPTH
6.0
5.0
4.0
3.0
2.0
1.0
0.0
MEAN DAMAGE
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
1
2
3
4
5
PACK

FIGURE 6.

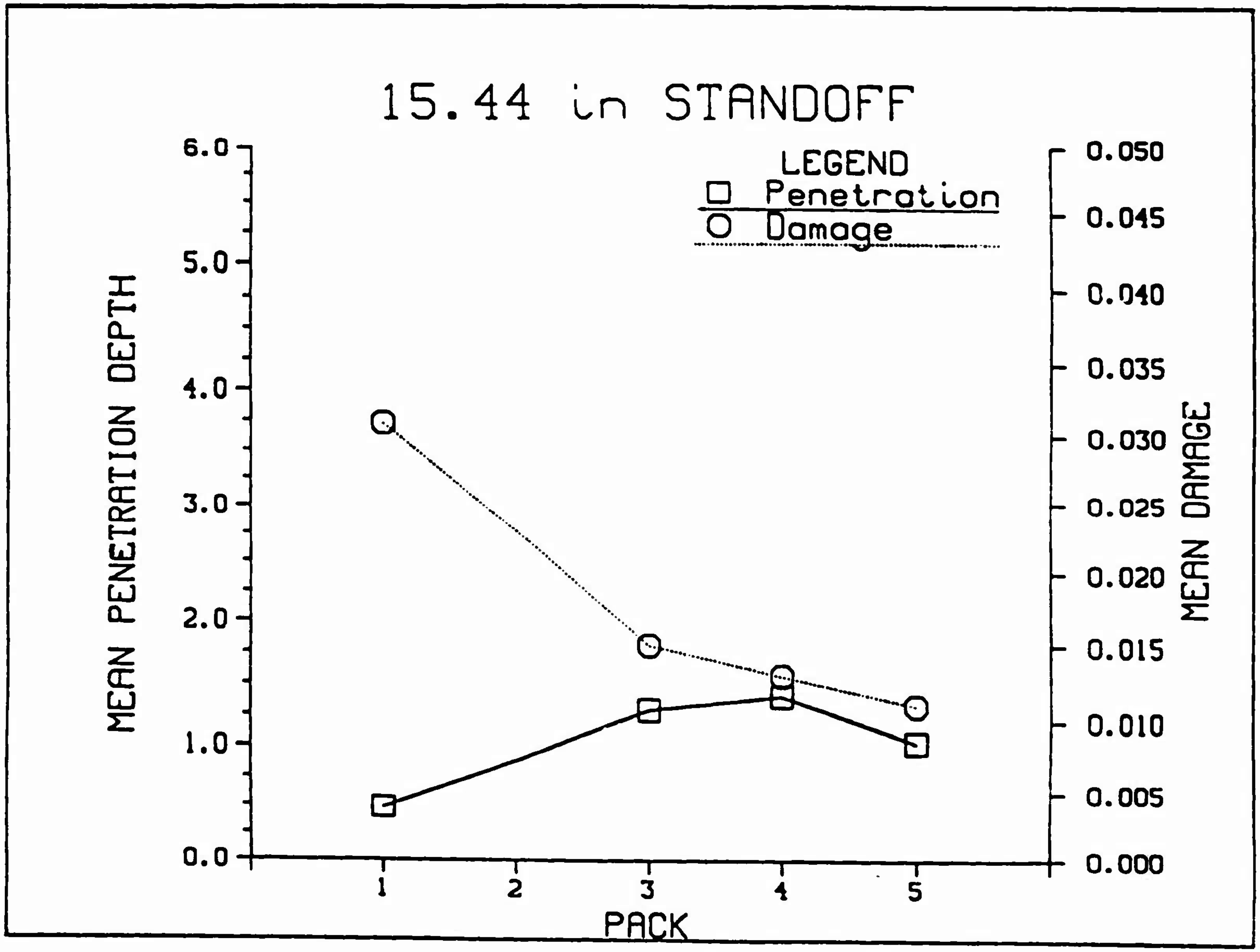

15.44 in STANDOFF
LEGEND
Penetration
Damage
MEAN PENETRATION DEPTH
6.0
5.0
4.0
3.0
2.0
1.0
0.0
MEAN DAMAGE
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
PACK
1
2
3
4
5

FIGURE 7.

At one point early in the analysis we flagged bomblets showing lower penetration depths as possibly coming from a different population. The relationship between Pack and those penetration depths being flagged is pointed out further in figure 8. Of fourteen bomblets positioned in pack one during the dispersing simulation, eleven were flagged for low penetration. Of fifteen bomblets positioned in pack two, nine were flagged for low penetration. Finally, of twenty seven bomblets flagged, twenty had been positioned in packs one or two during the dispersing simulation. Due to its unexpected effect on bomblet performance, Pack was determined to be our lurking variable.

Why did Pack have an effect on penetration depth? One possibility was proposed by a systems analyst familiar with MLRS munitions. In figure 5, note that steel plates were bolted to the top of pack five and to the bottom of pack one. Rather than being suspended in air, the test apparatus rested on the ground. When the charge within the canister was ignited, the shell of the canister, the bomblets, and the steel plate on pack five were blown out away from the center of the canister. The bottom steel plate remained stationary, pinned by the force of the explosion and the ground. Many bomblets from the lower packs caromed off this hard fixed surface, causing more severe deformation to themselves.

CONCLUSION

In conclusion, some information, not addressed here, could still be extracted from these experimental data, but problems created by the lurking variable hindered the intended complete analysis. It is interesting to note that heterogeneity of variance played a hero's role in this analysis, since investigation of this problem aided in the discovery of the lurking variable, Pack. Also, proper design made it possible to draw some conclusions in the face of unexpected circumstances. Finally, as suggested by Professor G.E.P. Box during this presentation, this example illustrates that statistical analysis can accomplish much more than hypothesis testing by lending insight to the physical environment, in this case by pointing out possible inadequacies in the test apparatus.

RATIO OF FLAGGED DATA POINTS TO THE NUMBER OF POINTS IN A CELL

		STANDOFF			
PACK	BUILT IN	3.86"	7.72"	15.44	TOTAL
1	0/3	2/2	3/3	6/6	11/14
2	0/0	2/6	7/9	0/0	9/15
3	0/3	0/3	0/0	2/6	2/12
4	0/3	0/4	2/6	0/3	2/16
5	1/9	1/3	0/0	1/3	3/15
TOTAL	1/18	5/18	12/18	9/18	

20 OF 27 FLAGGED DATA POINTS CAME FROM PACKS 1 AND 2

FIGURE 8.